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Investigation of the Effect of form of Orifices for the Pitot Tube

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INVESTIGATION OF THE EFFECT OF FORM OF ORIFICES FOR THE PITOT TUBE

BY

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THESIS

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

LOUIS SOLLIDAY KNORR

ENTITLED INVESTIGATION OF EFFECT OF FORM OF ORIFICE FOR THE PITOT TUBE

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Municipal and Sanitary Engineering

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Investigation of The Effect of Form of Orifices for The Pitot Tube.

The Pitot tube is a convenient instrument for measuring the velocity of water when the conditions of flow permit its use. The accuracy of the measurement depends upon the accuracy of the coefficient used in the Pitot tube velocity formula. Most writers consider that the value of this coefficient is dependent upon the form of the tip or mouthpiece of the instrument. It is necessary to determine the value of the coefficient for a given form of mouthpiece by rating it experimentally. For this thesis, experiments were made to determine the effect of different forms of mouthpieces and to establish values of the coefficients for these forms. The forms of mouthpiece used were (a) taper, (b) conical, (c) blunt, (d) offset taper. The sketches on page 7 show the details of these forms. Comparison is also made with the duplicate of the Mississippi River Commission Pitot Tube No. 10, the coefficient of which was found by Peterson. (Calibration of Pitot Tubes — Thesis by John Frederick Peterson — U. of I. '04)

The Pitot tube was invented by a French engineer by the name of Pitot in 1730. It was a bent glass tube

with open ends. When placed in the current with the mouth upstream, the velocity of the water would cause it to rise in the vertical piece to a height "h." "h" could be measured and the velocity could be determined from the relation $V^2 = 2gh$ or $V = \sqrt{2gh}$. Later a second tube was set at right angles to the first so that it pointed across the stream when the first was directed against the current.

The instrument was later improved by Darcy and Bazin. They used two tubes, one tapered to a point, the other had small holes through the sides. The tops of the tubes were connected and a partial vacuum caused the liquid to rise in the tubes to a height convenient for reading. Darcy and Bazin published their results in 1865. For the tube which they used, the value of c, in the formula $V = c\sqrt{2gh}$ was found to be approximately equal to unity. The Pitot tube has the advantage that it is not necessary to take time into consideration when determining the velocity. It has the disadvantage that the height "h" is usually small, so that an error in reading has a large influence upon the results.

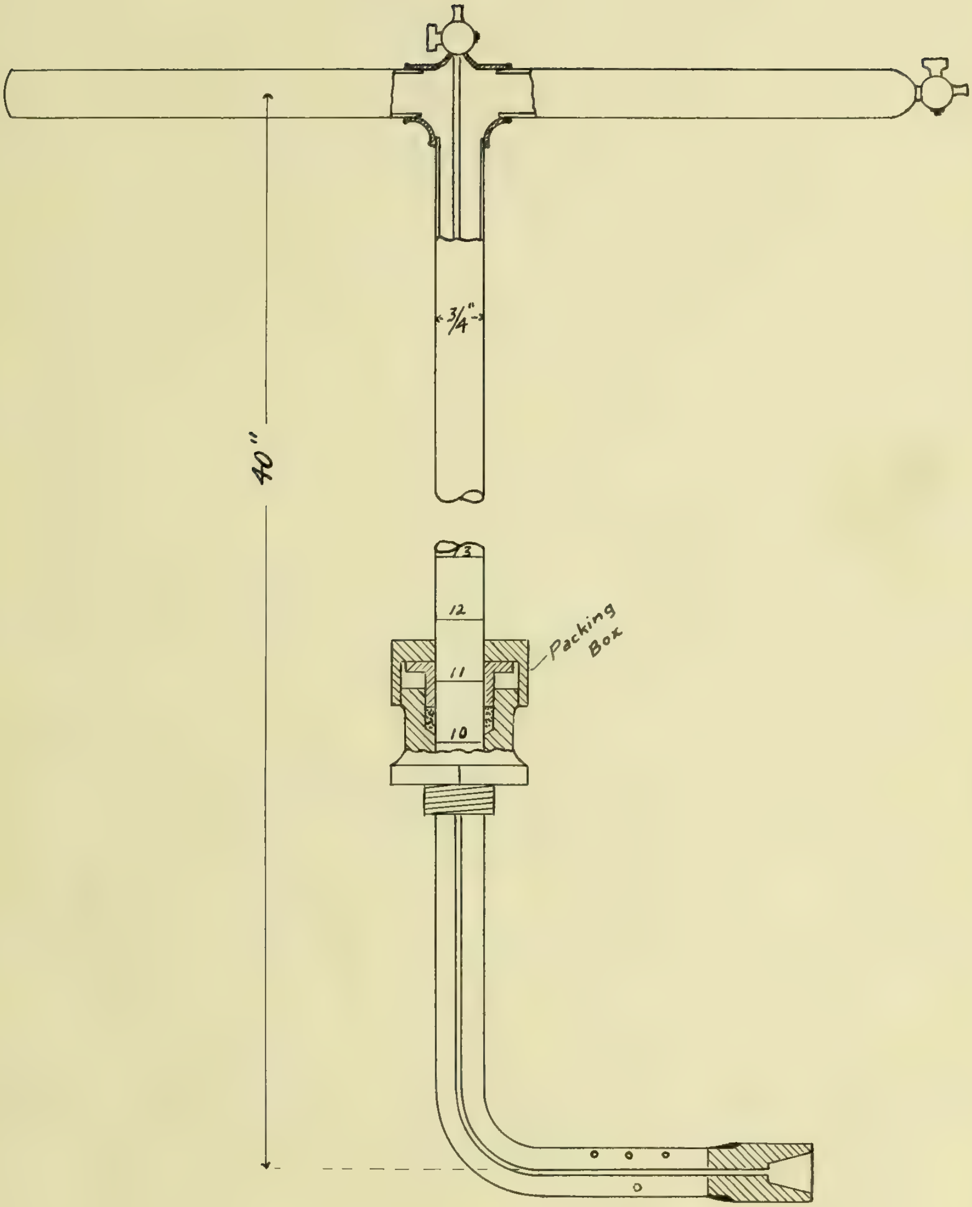
The Pitot tube was regarded as an instrument with a low degree of precision and nothing much was done with it until 1888. In this year Freeman (Transactions of American Society of Civil Engineers 1889,

Vol. 21) used an improved form of Pitot tube in some experiments on the velocities of jets from nozzles. He also made experiments on jets from 1⅛-inch tubes under high velocities. For a complete discussion of these experiments see the above volume. At different times during the period from 1888 to 1900, many experiments were made by Bazin, Cole, Williams, Hubbell and Fenkell, and the results obtained with the Pitot tube, by these men, established the fact that under proper conditions it is an instrument of precision for the measurement of velocities in pipes.

In the experiments here recorded, the Pitot tube was inserted in the 12 inch pipe line of the Hydraulics Laboratory of the University of Illinois. Water was pumped into the standpipe by the Snow pump, an overflow enabling a constant head of 25 feet to be maintained. The 12 inch pipe line was fed from the standpipe. The discharge was measured by means of the lower 3-foot weir at the north side of the laboratory. This weir was calibrated by Mr. A.C. Le Sourd, U of I '03. (Calibration of Weirs in the Hydraulics Laboratory of the University of Illinois — Thesis '03.)

The Pitot tube used in these experiments consists of two pipes, the outer one being ¾-inch in diameter and the

FIGURE 1



PITOT TUBE

inner tube $1/8$-inch in diameter. The small tube is called the impact or velocity tube, and the large tube is called the static tube. The $1/8$-inch tube is inside the $3/4$-inch tube and terminates in a $1/4$-inch cock. The outer tube has four holes of $1/16$-inch diameter to receive the static pressure. This outer tube also terminates in a $1/4$-inch cock. The instrument is shown in Fig. 1-page 4 without the mouthpiece. The inner and outer tubes are connected with the differential gauge by means of rubber tubing. The Pitot tube was moved backward and forward on a line through the stuffing box without any great leakage of water.

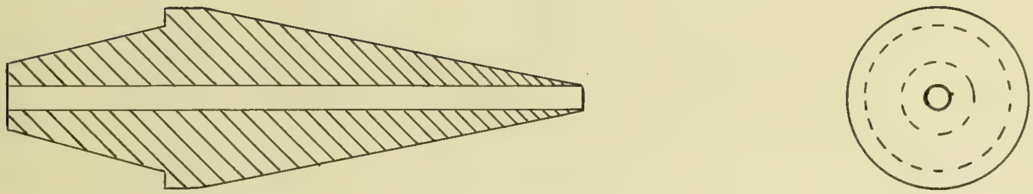
The differential gauge consisted of a U tube made of $1/4$-inch glass tubing and fastened to a thin board which had a strip of paper glued to it and marked in inches and tenths of inches. Each leg of the tube was about six feet long. The tube was partly filled with carbon tetrachloride, a colorless liquid with a specific gravity of about 1.6. Readings of this liquid were taken at intervals to determine the specific gravity. Since the specific gravity of the carbon tetrachloride is different from that of water, it was necessary to determine the head of water which corresponds to the actual head as read on the gauge. Let h' equal the head as read from the gauge, h the corresponding water head, and x the specific gravity of the liquid. The relation is $h = h'x - h' = h'(x-1)$

The relation between the velocity of the water and the head indicated by the gauge of the Pitot tube is expressed by the formula $V = c\sqrt{2gh}$ when V = velocity in feet per second, h = the head in feet of water shown by the differential gauge and c is an experimental coefficient for the given mouthpiece and instrument used. To simplify computations, a constant was derived which if multiplied by the square root of the gauge reading of h, in inches, will give the velocity in feet per second as registered by the gauge for a coefficient of unity. We have $v = \sqrt{2gh} = \sqrt{64.32\,h}$ By changing h to the equivalent water head which for a specific gravity of 1.6 equals $.6\,h$, we get $V = \sqrt{64.32 \times \frac{.6\,h}{12}}$ $= 1.79\sqrt{h}$ (h being in inches)

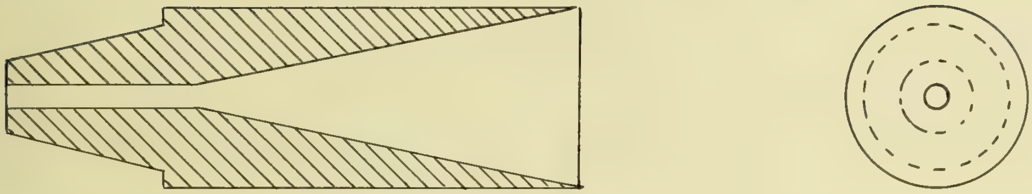
Since the velocity in a pipe varies throughout the cross section, it was necessary to traverse the diameter of the pipe with the instrument. The point of the tube was started as close to one edge of the pipe as possible, and readings were taken every even inch until the opposite side of the pipe was reached. The readings were the differences in level of the columns of carbon tetrachloride caused by the velocity of the water. The square roots of these differences were plotted and formed a curve. These plotted quantities are proportional to the velocities at the various points along a diameter. The pipe was divided into

FIGURE 2.

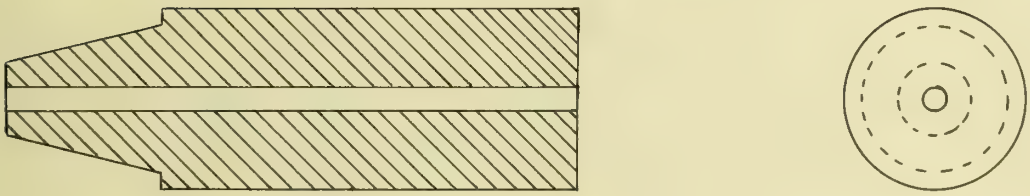
(a) Taper Mouthpiece



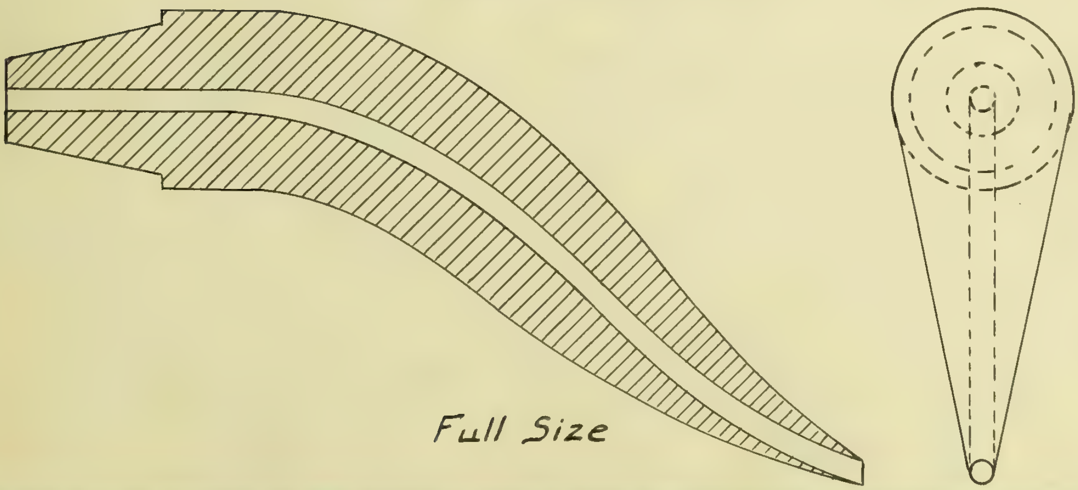
(b.) Conical Mouthpiece



(c) Blunt Mouthpiece



(d) Offset Mouthpiece



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concentric rings of equal width. The square root of the mean h for each ring was found and multiplied by the area of its ring. The mean $\sqrt{h}$ was found by dividing the sum of the products $(a_n \times h_n)$ by the area of cross section of the pipe.

The results are shown in tabular form on pages 18, 19 and 20. Curves showing the values and variations of $\sqrt{h}$ for different velocities and for different portions of the pipe are given on plates I, II, III and IV.

The ordinary mouthpiece will not permit readings being taken closer than 3/8 of an inch from the shell on the extreme side of the pipe. The construction of the instrument would not permit readings being taken closer than 2¼ inches from the shell on the near side of the pipe. A special mouthpiece with reversible offset (d-Fig. 2, Page 7) was designed to overcome these difficulties. A traverse of half or more of the pipe could be made with the mouthpiece in one position. The rest of the traverse could be made after the mouthpiece was reversed. It is necessary to take the tube out of the pipe to change the position of the mouthpiece. This required emptying the pipe. The velocity in the pipe was regulated by means of a valve till the reading for the center position was duplicated. The traverse was then completed.

Care was taken to get all the air out of the

instrument before starting with the readings. If, at the end of a series of experiments, the two columns of the differential gauge did not stand level, when the flow in the pipe was shut off, there was air in the instrument and these readings were discarded. Irregularities in readings were sometimes noticed. These were due to obstructions over the end of the tube which could usually be removed by moving the point at right angles to the direction of the traverse.

In a Pitot tube the effect of the current is to raise the level of water in the tube an amount equal to the velocity head $\frac{V^2}{2g}$. Besides this, there will be an impact effect from the water which strikes the face of the instrument and impinges upon the bore of the tube also. The amount of this additional effect will depend upon the form of the mouthpiece. It may be expected that with a thin-edged mouthpiece, the coefficient will approach unity, particularly if the mouthpiece be tapered or pointed in such a way as to obstruct the flow very little at the point of entrance. The conditions for this are fulfilled by the taper mouthpiece shown at (a) in Fig. 2. The conical mouthpiece ((b). Fig 2) is also thin edged and offers little opportunity for impact. It occupies a greater portion of the area of the pipe, the amount being 0.4% of the cross section of the 12-inch pipe. The blunt mouthpiece ((c) Fig 2) offers more surface for impact and for forming swirls and

transverse currents which go to modify the coefficient of the instrument. Since the mouthpiece of the Pitot tube not only receives the velocity head but also receives impact, the coefficient for a mouthpiece will take this into consideration. If h is given in terms of V the formula will take the form $h = \frac{1}{c^2} \cdot \frac{V^2}{2g}$.

In designing the forms of mouthpieces used, the taper mouthpiece ((a) Fig. 2) was included in order to compare it with the taper mouthpiece used in the Mississippi River Commission Pitot tube calibration by Peterson. The taper mouthpiece is not an exact duplicate of the Mississippi River Commission tube, and there is a difference in the values of c obtained. The coefficient for the Mississippi River Commission tube is .948 while that for this taper mouthpiece is .934. The reason for this variation is not known unless it lies in the fact that the Mississippi River Commission tube mouthpiece does not taper evenly as does the taper mouthpiece used in these experiments.

The conical mouthpiece was chosen in order to determine the difference between outside taper ((a) Fig. 2) and inside taper ((b) Fig. 2) It was expected that the water would crowd into the entrance of the conical mouthpiece and thus give higher gauge readings. It would seem that this does happen to a limited extent, because the coefficient for this mouthpiece is lower than that of the taper mouthpiece. The

coefficient determined for the taper mouthpiece is .934 and for the conical mouthpiece is .913. However this decrease is not very great. A mouthpiece like the conical one used in these experiments offers better place for the lodgment of floating material, hence it will become clogged more rapidly than other forms. It may be said here that care must be taken to protect the sharp edge of this mouthpiece, because it is very thin and its efficiency may be easily lowered by battering this edge.

In order to find the effect of not cutting out the conical opening made in mouthpiece (b) Fig. 2, the blunt mouthpiece shown in (c) Fig. 2 was devised and made. It was expected that this mouthpiece would offer such a surface for impact that eddies and swirling currents would form about the entrance and thus cause a much different coefficient than the others. The coefficient for this mouthpiece was found to be .890 Evidently the thickness of the point affects the coefficient and impact and swirling currents do affect the results.

As was stated on page 8, readings could not be taken close to the shell of the pipe with the ordinary mouthpieces. The special mouthpiece, (d) Fig 2) designed to overcome this difficulty was satisfactory in this respect, except that a complete traverse could

not be made without taking the instrument out and changing the position of the mouthpiece. The coefficient obtained for this instrument 1.07 is considerably higher than that of the other mouthpieces, a result which had not been anticipated. No explanation that is fully satisfactory can be given. Possibly the difference may be due to the swirling currents caused by the offset. Possibly the fact that the static openings are in a different circular ring of the pipe, where the velocity is different, may have a bearing on the result. If the pressure head throughout the cross section of a pipe flowing full is equal, this would not be true, but some engineers doubt this and claim that the pressure head changes as well as the velocity head. The entrance holes for the pressure head are at least 1½-inches distant radially from the orifice of the mouthpiece. This gives room for some variation, if the pressure head is not constant throughout the cross section of the pipe. The experimental coefficients obtained for this mouthpiece ran very uniformly. The experiments were made under favorable conditions, and it is believed that the average value may be relied upon.

Taking everything into consideration, the taper mouthpiece is the best for practical use. It is thin edged, offers practically no surface for impact, occupies

but a very small portion of the cross section of the pipe, is easily handled and is not so liable to clogging or injury. The conical mouthpiece has a crowding effect at the entrance and the blunt mouthpiece offers more surface for impact. The offset taper mouthpiece gave a high coefficient, but this coefficient remained nearly constant throughout the experiments. However, the offset taper mouthpiece is of such a form that its use would not be permissible in many cases where the taper mouthpiece could be used.

PLATE I

RESULTS WITH TAPER MOUTH PIECE

Table of results

	V	V'	C
1.	1.21	1.18	1.025
2.	2.29	2.65	.865
3.	3.63	3.82	.950
4.	4.51	4.88	.925

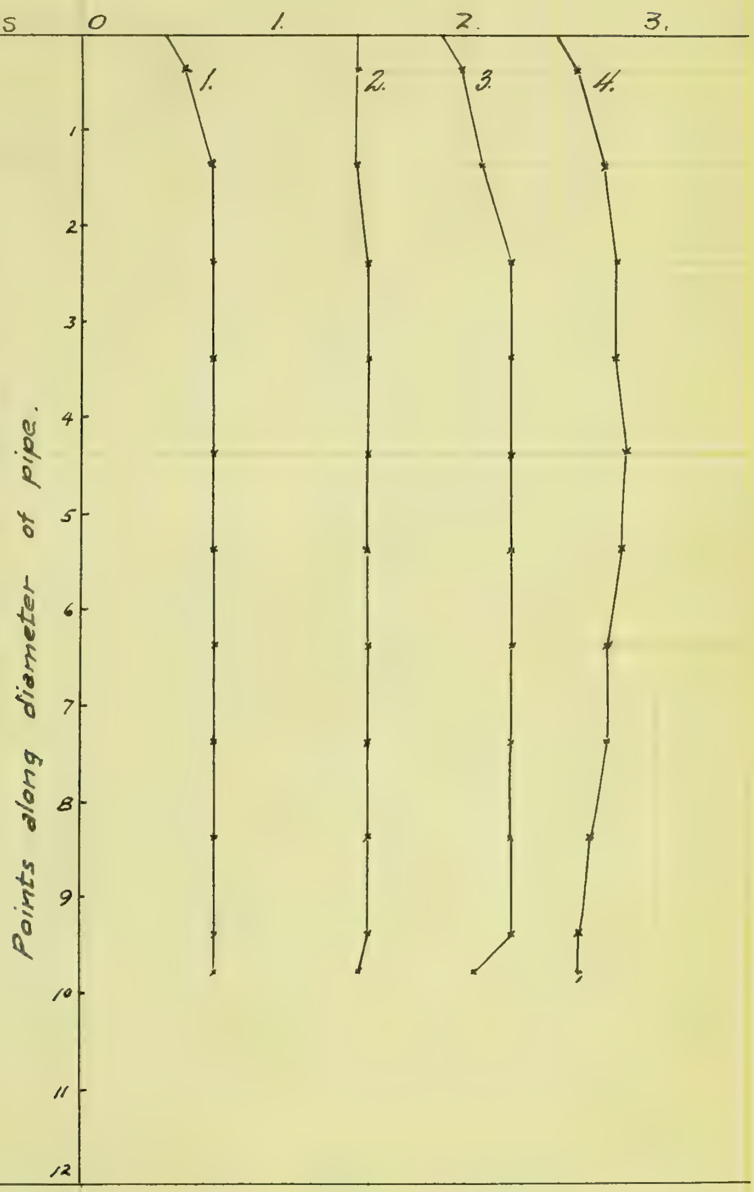


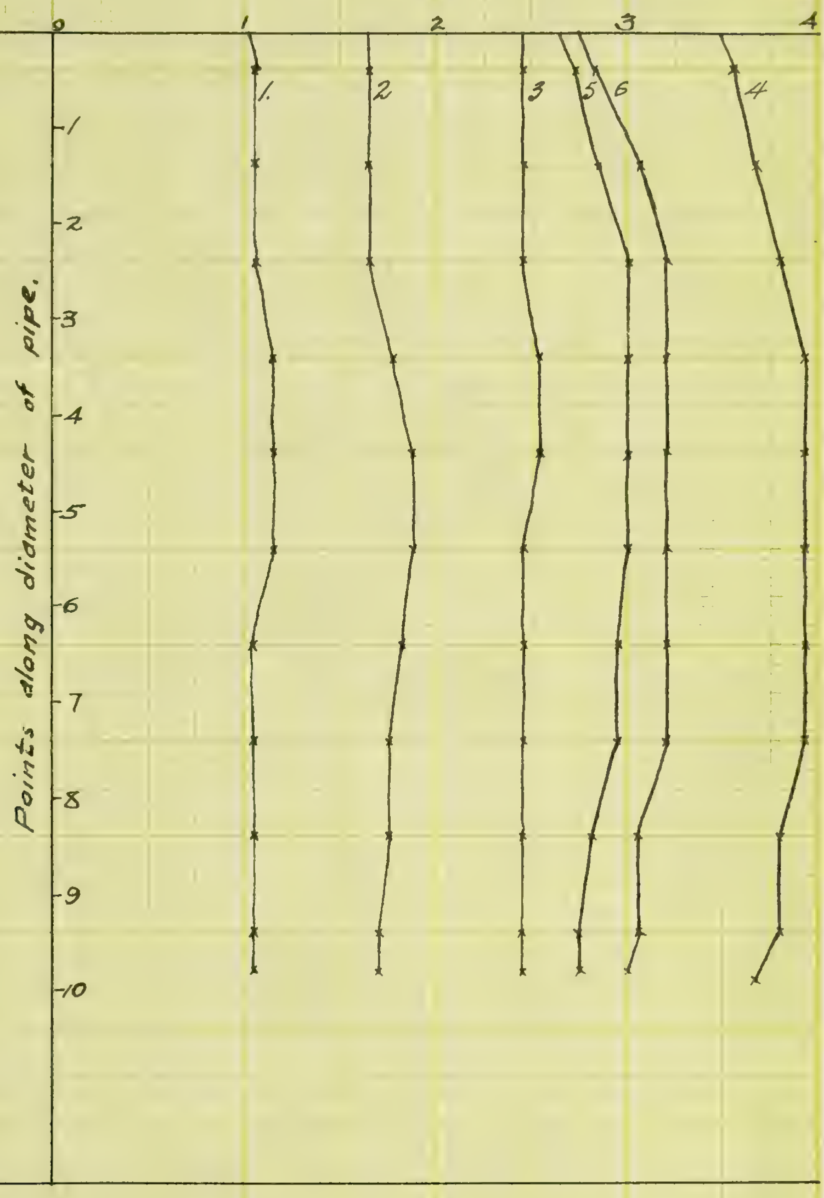
PLATE II

RESULTS WITH CONICAL MOUTHPIECE

$\sqrt{h}$ in inches

Table of results.

V	V'	C
1. V=1.62	1.91	.850
2. V=2.67	3.04	.880
3. =3.63	4.92	.898
4. 6.10	6.68	.915
5 4.58	5.10	.920
6 4.90	5.44	.900



EUGENE DIETZGEN CO., CHICAGO

PLATE III

RESULTS WITH BLUNT MOUTHPIECE

Table of results

	V	V'	C
1	0.599	.720	.832
2	1.32	1.57	.841
3	2.86	3.10	.923
4	4.01	4.37	.918
5	1.46	1.67	.875

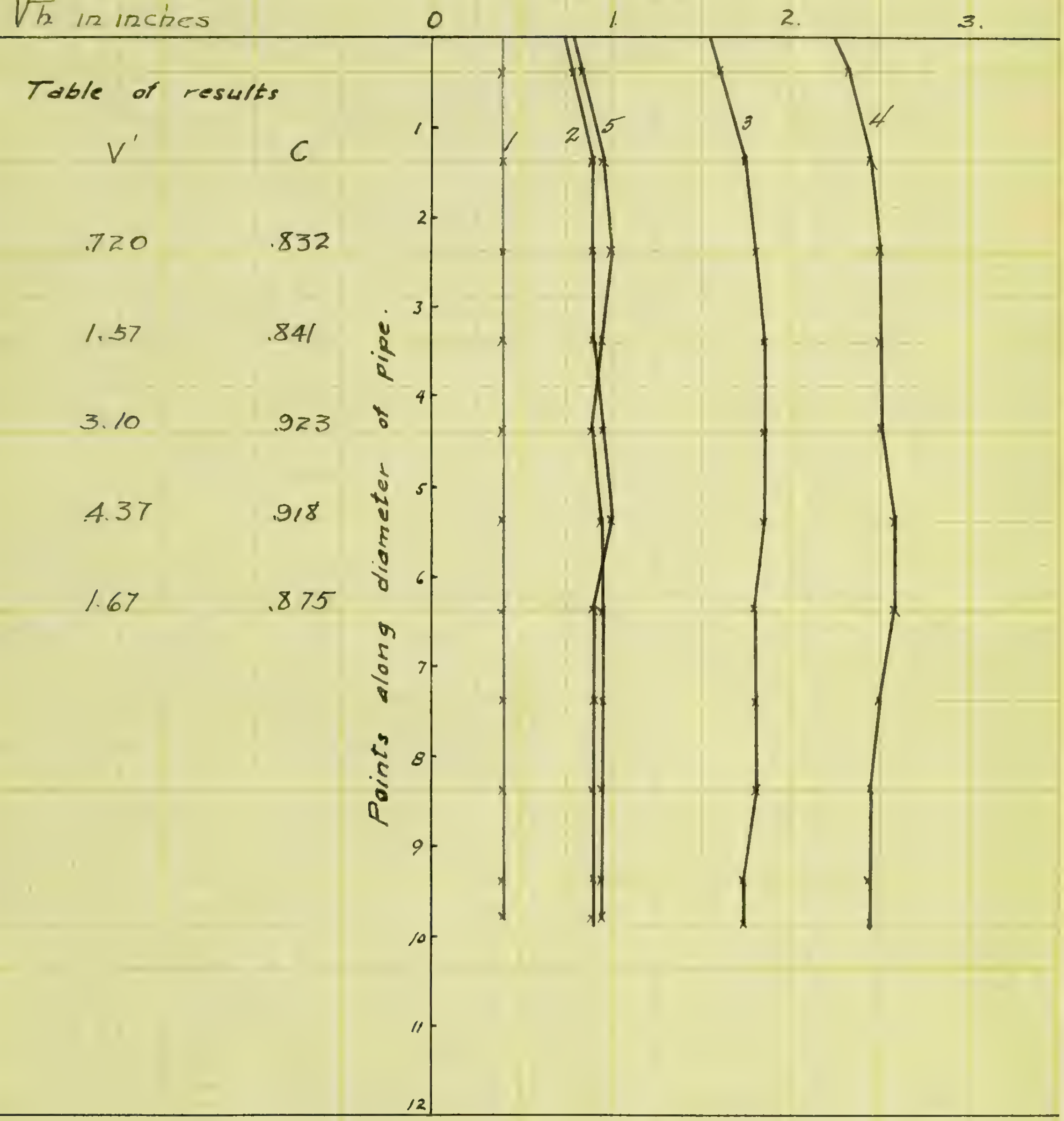


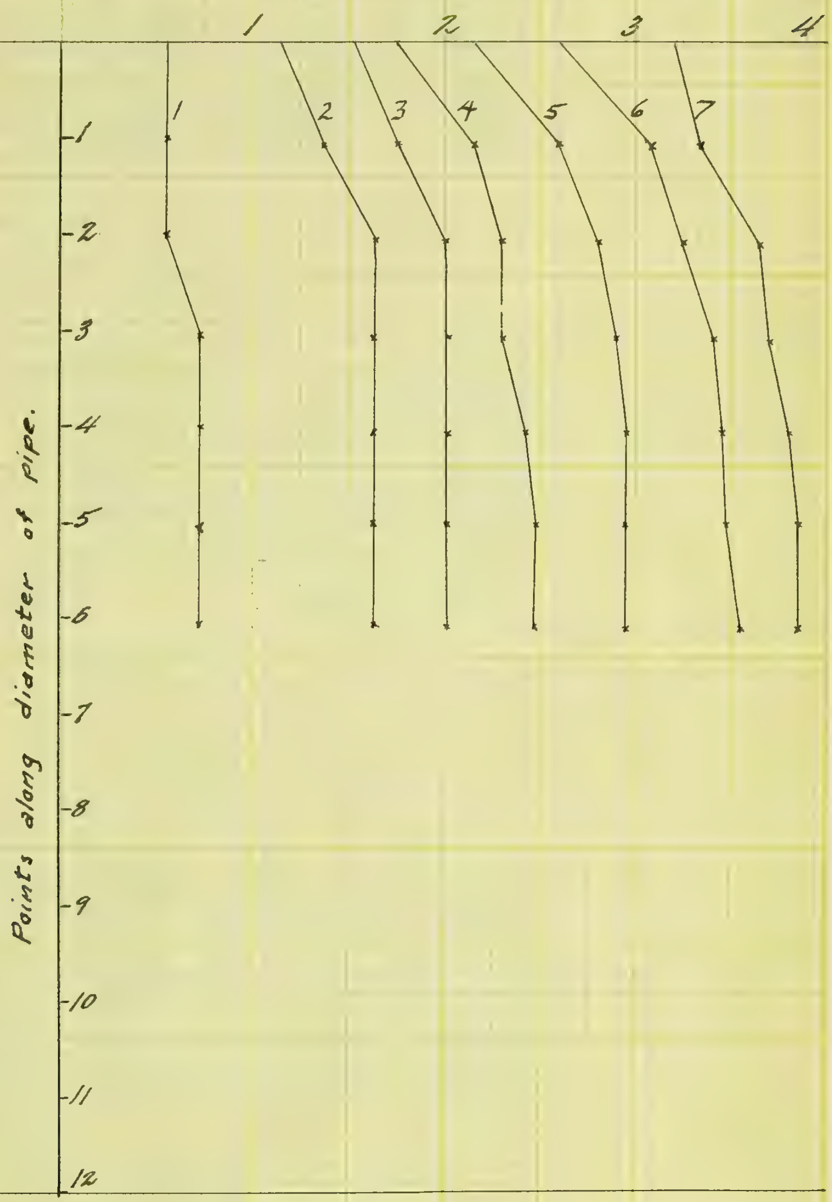
PLATE IV

RESULTS WITH OFFSET MOUTHPIECE

$\sqrt{h}$ in inches

Table of results

	V	V'	c
1	1.18	1.10	1.07
2	2.86	2.67	1.07
3	3.54	3.34	1.06
4	4.29	3.95	1.08
5	5.41	4.80	1.13
6	6.25	5.68	1.10
7	7.82	6.35	1.23



Note – Owing to a defect in the apparatus, only half of the pipe could be traversed

[illegible]

TABLE 1.

Results with taper mouthpiece – Horizontal.

No.	Mean $\sqrt{h}$	V' $1.79 \times \sqrt{h}$	Actual V	V/V'
1	.657	1.18	1.21	1.025
2	1.480	2.65	2.29	.865
3	2.140	3.82	3.63	.950
4	2.720	4.88	4.51	.925

Results with Taper mouthpiece Vertical–

No.	Mean $\sqrt{h}$	V' $1.79 \times \sqrt{h}$	Actual V	V/V'	
1	.284	.508	.25	.492	*
2	.552	.988	.76	.770	*
3	1.525	2.730	2.54	.934	
4	2.001	3.590	3.18	.886	
5	2.740	4.900	4.70	.960	

Mean $C = .934$

TABLE 2

Results with Conical mouthpiece – Horizontal.

No	Mean $\sqrt{h}$	V' $1.79 \times \sqrt{h}$	Actual V	V/V'	
1	1.065	1.91	1.62	.850	
2	1.698	3.04	2.67	.880	
3	2.470	4.92	3.63	.739	*
4	3.730	6.68	6.10	.915	
5	2.850	5.10	4.58	.920	
6	3.035	5.44	4.90	.900	

Results with Conical mouthpiece – Vertical.

No.	Mean $\sqrt{h}$	V'	Actual V	V/V'
1	1.000	1.79	1.65	.922
2	1.760	3.15	2.93	.930
3	2.270	4.06	3.69	.910
4	2.750	4.92	4.58	.932
5	2.970	5.32	4.90	.922
5	3.678	6.40	6.18	.965

Mean $C = .913$

Note – Values marked * not used for mean.

TABLE 3.

Results with Blunt mouthpiece – Horizontal.

No.	Mean $\sqrt{h}$	V' $1.79 \times \sqrt{h}$	Actual V	V/V'
1	.401	.720	.599	.832
2	.876	1.57	1.32	.841
3	1.73	3.10	2.86	.923
4	2.44	4.37	4.01	.918
5	.935	1.67	1.46	.875

Results with Blunt mouthpiece. – Vertical

No	Mean $\sqrt{h}$	V' $1.79 \times \sqrt{h}$	Actual V	V/V'
1.	.311	.557	.445	.800
2	.736	1.320	1.335	1.010
3	1.32	2.36	2.29	.971
4	2.56	4.59	4.39	.957
5	.70	1.25	1.08	.865
6	.311	.557	.445	.800

Mean C = .890

TABLE. 4.

Resuts with offset mouthpiece. – Horizontal.

No.	Mean $\sqrt{h}$	V' $1.79 \times \sqrt{h}$	Actual V	V/V'
1	.612	1.10	1.18	1.07
2	1.49	2.67	2.86	1.07
3	1.86	3.34	3.54	1.06
4	2.20	3.95	4.29	1.08
5	2.68	4.80	5.41	1.13
6	3.16	5.68	6.25	1.10
7	3.55	6.35	7.82	1.23

Results with offset mouthpiece - Vertical.

No.	Mean	V'	Actual V	V/V'
1.	.90	1.61	1.59	.989
2.	1.59	2.85	3.02	1.060
3.	1.87	3.35	3.56	1.060
4.	2.22	3.97	4.20	1.06
5.	2.74	4.90	5.21	1.06
6	3.34	5.98	6.35	1.06
7.	3.56	6.39	6.75	1.06

Mean C = 1.07

TABLE 5

- Mean Values of C -

Mouthpiece	Mean C
Taper	.934
Conical	.913
Blunt	.890
Offset	1.07